

**Effects of Parasitism by *Banchus flavescens*  
(Hymenoptera: Ichneumonidae) and *Microplitis mediator*  
(Hymenoptera: Braconidae) on the Bertha Armyworm, *Mamestra  
configurata* (Lepidoptera: Noctuidae)<sup>1</sup>**

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*Abstract.*—The bertha armyworm, *Mamestra configurata* Walker (Lepidoptera: Noctuidae), is an important pest of canola (*Brassica napus* L. and *B. rapa* L.) and flax (*Linum usitatissimum* L.) in western Canada. It is the focus of research to develop a management program integrating microbial and insect parasitoid agents with cultural practices and judicious use of chemical insecticides. To develop IPM effectively it is essential to understand the impact of parasitism on feeding activity of the host. We studied the effect of parasitism by two solitary koinobiont larval endoparasitoids: *Banchus flavescens* Cresson (Ichneumonidae) is a native parasitoid of *M. configurata*; and the European *Microplitis mediator* (Haliday) (Braconidae) is a candidate for introduction to enhance the biological control effected by *B. flavescens*. Parasitism by *B. flavescens* resulted in significantly decreased food consumption and lower biomass production but did not reduce the time that the pest would occur in the crop. Host larvae parasitized by *M. mediator* showed a much greater reduction in food consumed, weight gained, frass produced and the host's feeding time compared to nonparasitized larvae or those parasitized by *B. flavescens*. Management strategies should consider options that would minimize impact on parasitized larvae and introduction of *M. mediator* could benefit integrated management programs for *M. configurata*.

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The bertha armyworm, *Mamestra configurata* Walker, native to North America, has been the focus of studies to determine the role of natural control agents for this pest of canola (*Brassica napus* L. and *B. rapa* L.: Brassicaceae) and flax (*Linum usitatissimum* L.: Linaceae), the two most important oilseed crops grown in western Canada. Important natural control agents of larval stages of the bertha armyworm include viral and fungal diseases and parasitic wasps and flies (Wylie 1977, Wylie and Bucher 1977, Arthur and Mason 1985, Turnock 1988, Erlandson 1990). The solitary koinobiont ichneumonid *Banchus flavescens* Cresson is the single most

important larval parasitoid, occurring in more than 90% of bertha armyworm sampled in years when populations are declining (Turnock and Bilodeau 1984, Arthur and Mason 1985) yet *B. flavescens* is unable to prevent outbreaks from occurring (Mason *et al.* 1998).

Biologically based pest management strategies being developed for the bertha armyworm include microbial insecticides (nuclear polyhedrosis virus, MacoNPV (Erlandson 1990)) and introduction of exotic parasitoids to complement the mortality caused by native natural enemies. It is essential to understand the impact of parasitoids on the host's feeding activity so that management strategies can be developed to minimize the impact on parasitoids.

The solitary koinobiont braconid parasitoid *Microplitis mediator* (Haliday) has been

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studied as a candidate for introduction to enhance natural biological control of *M. configurata*. *M. mediator* attacks the cabbage moth, *Mamestra brassicae* (L.), in its native habitat in Europe (Slovak 1985a, 1985b, Johansen 1997). It is synchronized with its host in both uni- and bivoltine systems. Arthur and Mason (1986) demonstrated that *M. mediator* will attack and successfully parasitize 1<sup>st</sup> to 3<sup>rd</sup> instar bertha armyworm larvae, although 3<sup>rd</sup> instars frequently repel or injure female wasps attempting to oviposit. The fully developed parasitoid larva egresses from the host's 4<sup>th</sup> instar, regardless of the instar parasitized (Mason, unpublished) while non-parasitized larvae complete 6 instars and then pupate.

Evaluation of the impact of candidate biological control agents on the target ecosystem is a necessary component of biological control screening projects. An important part of this process is to determine the effect of the agent on the crop being protected. Although idiobiont parasitoids normally kill the host immediately (eliminating further plant feeding) koinobiont insect endoparasitoids generally do not kill immediately and permit feeding by the host for at least a short period of time after parasitization (Askew and Shaw 1986, Quicke 1997). Thus, determination of the effect of koinobiont parasitism on the host's feeding is an indirect means for determining the impact of parasitoids on the crop being protected. Depending on parasitoid biology, parasitism can reduce (Rahman 1970, Guillot and Vinson 1973, Brewer and King 1978, Sajap *et al.* 1978, Brewer and King 1980, Parkman and Shepard 1981, Shaw 1981, Powell 1989, Kumar and Ballal 1992, Ohnuma and Kainoh 1992, Khan 1994, Yang *et al.* 1994, Harvey 1996), increase (Rahman 1970, Hunter and Stoner 1975, Byers *et al.* 1993) or have no effect on (Brewer and King 1981) feeding by lepidopteran host species. Parasitoids that elicit decreased feeding by the host reduce potential damage to the crop in addition to removing the

host from the reproductive pool for subsequent generations.

The application of insecticides for control of bertha armyworm usually takes place during the pod development stage of canola, when the larvae are in the 5<sup>th</sup> and 6<sup>th</sup> instars. The decision to apply insecticides is based on evidence of real or potential (often visibility of larvae) crop damage. Because insecticides may have a negative impact on adult and larval parasitoids, understanding parasitoid biology is important to develop sound pest management strategies. Arthur and Mason (1985, 1986) showed that *B. flavescens* and *M. mediator* oviposit in 1<sup>st</sup> to 3<sup>rd</sup> instar bertha armyworm which are inconspicuous and feed on canola leaves before pods develop. Because no control measures are taken during these life stages of the pest, adult *B. flavescens* and *M. mediator* are not exposed to insecticides when they are searching in the foliage of the canola crop. Further, they are unlikely to be present when insecticides are applied during the 5<sup>th</sup> and 6<sup>th</sup> larval instars because the preferred instars for oviposition are not present. In contrast, parasitized host larvae may still be present when insecticides are applied. For example, parasitoid species that prolong development of the host by increasing or making no difference in the amount of food consumed by the pest are more likely to be indirectly exposed to and negatively impacted by control measures such as chemical insecticides that kill on contact and are usually used against mature larvae. Parasitoid species that reduce food consumption are less likely to be affected because they tend to shorten the life of the host and reach a life stage (i.e. form protective cocoons) in which insecticides may not kill them. Thus, the impact of parasitism on the host's feeding may affect plans for biological control introductions in integrated pest management (IPM) programs (Hunter and Stoner 1975). In this study we assessed the effect of parasitism by the native ichneumonid *B. flavescens*

and the exotic braconid *M. mediator* on *M. configurata* growth and food consumption.

## MATERIALS AND METHODS

Hosts used in the experiments were from a *M. configurata* colony maintained on artificial diet (Bucher and Bracken, 1976). Parasitoids used in the experiments were derived from populations collected in Saskatchewan, Canada (*B. flavescens*) and central Switzerland (*M. mediator*). The *B. flavescens* females used in the experiments were reared from overwintered cocoons collected in the spring and maintained at  $21 \pm 1^\circ\text{C}$  and 16:8 L:D. The *M. mediator* was maintained in laboratory culture on *M. configurata* (Arthur and Mason, 1986). All plants used were canola, *Brassica napus* L. variety Westar. All experimental individuals were maintained at  $21 \pm 1^\circ\text{C}$  and 16:8 L:D.

For each of the experimental trials (3 for *B. flavescens* and 4 for *M. mediator*), 30 2nd instar larvae from the same egg mass were selected. The larvae were divided into three groups of 10 and individuals of each group weighed. Whole canola leaves (approximately  $7 \times 6$  cm) clipped at the petiole from growth cabinet grown plants were used in all food offerings and dry weight determinations. Larvae of one group were placed in individual 52mm diameter  $\times$  21mm deep petri dishes containing a canola leaf on moistened filter paper in 45 mm diameter petri dishes. Larvae of a second group were individually parasitized (under observation) by *B. flavescens* or *M. mediator* and placed on canola leaves in the manner described above. The third group of larvae were individually weighed (wet weight) with a Mettler analytical balance (Model AG245), frozen, dried (48 h @  $60^\circ\text{C}$ ), and then individually weighed (dry weight). The larvae were weighed and given fresh leaves at intervals (2–4 day) during each trial. The fresh weight of each leaf disc was recorded before introduction into the petri dish. Fresh and dry weights (48 h @  $60^\circ\text{C}$ ) were re-

corded separately and dry weight ratios (dry weight  $\div$  initial fresh weight) were calculated. The frass produced by each larva was collected at the end of each feeding period and stored in a plastic petri dish. The pooled amount for the experimental period was dried (48 h @  $60^\circ\text{C}$ ) and weighed. Similarly the fresh:dry weight ratios were determined for all larvae after parasitoid egression for parasitized individuals and at pupation for non-parasitized larvae.

Nutritional indices were initially considered (Waldbauer 1968, Kogan 1986), but Schmidt and Reese (1986) pointed out that these indices can be misleading due to the error introduced during initial measurements of dry matter of the food source, quantity of food eaten, and the weight of feces produced. These errors accumulate and are amplified in the calculation of the nutritional indices (Raubenheimer and Simpson 1992). Van Loon (1991) describes more precise techniques including indigestible markers, elemental budgets, planimetry, and respirometry. Thus, we calculated only:

*Food consumption* (F) = [(Mean Dry Weight of Control Food Portions / Mean Wet Weight of Control Food Portions)  $\times$  Initial Wet Weight of Food Portions] – Dry Weight of Food Portions after feeding;

*Total Food Consumed* (TC) =  $i \Sigma F$ , where  $n$  is the number of feeding intervals (to parasitoid egression or host pupation);

*Total Dry Weight Produced* (DWT) = Dry Weight at host pupation or parasitoid egression (host + parasitoid) – Mean Dry Weight (of control group) at the beginning of the experiment.

The *B. flavescens* data were analysed using analysis of variance (Proc GLM, SAS 1992) to determine if parasitism significantly affected the variables measured. The effects of parasitism by *M. mediator* were so obvious that statistical analyses

Table 1. Mean value for development time (days)(DT), total dry weight (mg)(of pupa or parasite larva + larval skin produced)(DWT), total mg dry weight of frass produced (Frass), and total mg dry weight consumed (TC) for non-parasitized and *B. flavescens*-parasitized *M. configurata*.

Index	Trial #1		Trial #2		Trial #3		Pooled	
	NP	P	NP	P	NP	P	Mean	SEM
DT	21.4*	21	19.2	19.3	20.1	21	20.3	0.2
DWT	83.2	32.8 <sup>a</sup>	57.2	32.3 <sup>b</sup>	80.2	46.7 <sup>a</sup>	53.3	3.5
Frass	142.9	117.3	185	127.0 <sup>b</sup>	138	166.9	148.2	6.1
TC	415.3	318.9 <sup>c</sup>	406.5	228.4 <sup>a</sup>	371	297.6 <sup>c</sup>	334.9	12.6

\*approximate standard error of the mean for a trial mean can be obtained by multiplying the pooled SEM by 1.7. For each trial significant differences owing to parasitism are indicated by: <sup>a</sup> = ( $P < 0.001$ ), <sup>b</sup> = ( $P < 0.01$ ), <sup>c</sup> = ( $P < 0.1$ ).

were not necessary (a non-parametric test could have been used).

## RESULTS

*Banachus flavescens*.—In all experimental trials, nonparasitized (NP) *M. configurata* larvae consumed significantly more food and gained significantly more weight than did parasitized (P) larvae (Table 1). There was no significant difference in the number of days required to complete development. From the beginning of the trial it took *M. configurata* 18–24 days to develop to the pupal stage and development of *B. flavescens* from oviposition to larval egression was completed in 19–24 days. However, in spite of minor differences among trials on some dates, overall the only variable which showed a significant trial  $\times$  treatment interaction, that is differences in pattern from trial to trial, was the dry weight of frass produced.

While Fig. 1a and b are representative of the patterns observed in all three trials, owing to individual variability within trials (especially because some values were much higher or lower than all others in a group) differences in weight and food consumed by the parasitized and non-parasitized groups were not always consistent, on specific dates, from trial to trial. Consumption of food peaked at 14–18, 16–19 and 11–14 days in trials 1–3, respectively. Food consumption declined markedly after the peak, coinciding with the beginning of the prepupal stage in non-parasitized hosts and the pre-emergence period of the parasitoid.

*Microplitis mediator*.—In all experimental trials non-parasitized (NP) *M. configurata* larvae consumed dramatically more food, gained much more weight and produced much more frass than did parasitized (P) larvae (Table 2). Feeding and develop-

Table 2. Mean value for development time (DT), total dry weight (of pupa or parasite larva + larval skin produced (DWT)), total mg dry weight of frass produced (Frass), and total mg dry weight consumed (TC) for non-parasitized and *M. mediator*-parasitized *M. configurata*.

Index	Trial #1		Trial #2		Trial #3		Trial #4		Pooled SE	
	NP	P	NP	P	NP	P	NP	P	NP	P
DT	21	12	21	11.4	21	12.3	21	11	0	0.2
DWT	67.6	2.8	62.4	1	77.8	3.8	81.2	2.6	4.2	0.02
Frass	182.6	5.1	209	4.5	161	7	213	12.7	8.3	0.1
TC	402	13	593	82	294	31	356	47.6	26.1	13.9

\*approximate standard error of the mean for a trial mean can be obtained by multiplying the pooled S.E.M. by 2.0.



ment to the pupal stage of non-parasitized *M. configurata* reared from neonate larvae at  $21 \pm 1^\circ\text{C}$  takes 21–25 days (unpublished data). Parasitized larvae ceased to consume food, once *M. mediator* larvae egressed and formed cocoons (11–14 days after parasitism), a markedly shorter period than the food consumption period for non-parasitized *M. configurata* larvae.

Non-parasitized larvae weighed and consumed significantly more beginning 4–8 and 8–11 days, respectively, after trials were initiated. The trends represented in Figure 2a and b for trial #1 were typical. For non-parasitized larvae consumption of food and larval weights peaked 15–17, 13–15, 11–13, and 13–15 days after parasitism in trials 1–4, respectively. Both consumption and weight declined after this peak, coinciding with the beginning of the prepupal stage. For parasitized larvae, larval weight did not increase beginning 4–8 days after the trials were initiated. Food consumption showed only a small increase in trial #2, while actually decreasing in the other three trials beginning 0–4 days after trials were initiated. In all trials food consumption by parasitized larvae ceased by day 13, 7 days before non-parasitized larvae ceased feeding.

## DISCUSSION

Synchronization of the completion of larval development of *B. flavescens* and *M. configurata* is consistent with results by Slovak (1987) for another Banchini, *Exestastes cinctipes* Retzius (Hymenoptera: Ichneumonidae), parasitizing *M. brassicae*. He found that at  $20^\circ\text{C}$  development to parasitoid cocoon formation took 25.3–26.6 days while non-parasitized larvae took 26.4–26.7 days to form pupae. These development times are 5–6 days longer than those we observed at  $21.0 \pm 1.0^\circ\text{C}$  for *B. flavescens* parasitizing *M. configurata*. Slovak (1987) also noted that at 20 or  $24^\circ\text{C}$  parasitized host larvae entered the soil significantly earlier (2.1–3.0 and 3.5–3.9 days, respectively) than non-parasitized

larvae. Although we did not study this behaviour, it may also occur in the *B. flavescens*/*M. configurata* parasitoid/host system because, as reported by Arthur and Mason (1985), the parasitoid forms a cocoon in which it overwinters within the earthen cell formed by the host larva just before being killed.

That parasitism by *B. flavescens* significantly reduced the total amount of food consumed by *M. configurata* (20–44%) is reflected in the fact that parasitized larvae produced significantly less (39.4–58.2%) dry protein matter than non-parasitized larvae. Although not directly comparable, these results are similar to findings for solitary koinobiont Campoplegine species attacking Lepidoptera (Khan 1994, Kumar and Ballal 1992, Yang *et al.* 1994, Doucet and Cusson 1996). Only Doucet and Cusson (1996) measured frass production, and found that non-parasitized larvae produced 38% more frass than parasitized larvae. In contrast, about 10% more frass was produced by non-parasitized than parasitized larvae in two of three trials and 10% less in the third trial in our study. It is not clear why frass production by parasitized larvae in one of our three trials was greater than for nonparasitized larvae.

Development of *M. mediator* to egression took 11–14 days, about 1/3 less time than for *B. flavescens*. Egression of mature *M. mediator* larvae occurs just after the host molts to the 4<sup>th</sup> larval instar even if parasitized in the 3<sup>rd</sup> instar and, as noted by Shaw and Huddelston (1991) for other *Microplitis* spp., the cocoon is formed beneath the host which remains alive for several days without feeding (Mason, unpublished). Behavioral modification of *M. configurata* hosts by mature larval *M. mediator* parasitoids has been observed in the laboratory (Pivnick 1993). Parasitized host larvae moved to the leaf litter and senescent leaves that become part of the litter where parasitoid pupation took place. This was confirmed in the field where cocoons successfully overwintered (Mason,

unpublished). In both situations very few parasitoid cocoons were found on standing plant parts that are harvested.

Parasitism of *M. configurata* by *M. mediator* clearly had a greater impact on the amount of food consumed by the host than parasitism by *B. flavescens* (Figs. 1b and 2b). The results observed for *M. mediator* are consistent with those observed for solitary koinobiont Microgastrinae Braconidae parasitoids attacking Lepidoptera in other systems (Rahman 1970, Sajap *et al.* 1978, Parkman and Shepard 1981, Tanaka *et al.* 1984, Powell 1989). In contrast, Lepidopteran hosts parasitized by at least some gregarious koinobiont Braconidae and polyembryonic Encyrtidae species consume significantly more than non-parasitized hosts and take longer to develop (Rahman 1970, Hunter and Stoner 1975, Gobbi *et al.* 1993, Byers *et al.* 1993).

The decrease in feeding and weights after a maximum peak is reached (Figs. 1 and 2) is linked to cessation of feeding and gut evacuation associated with prepupal development in non-parasitized larvae, and probably to cessation of feeding by parasitized larvae which move to the leaf litter (*M. mediator*, see Pivnick 1993) or form earthen cells (*B. flavescens*, see Arthur and Mason 1985) where they complete development and pupate. The different times to peak weights and consumption between trials may be related to differences in food quality, although the same plant variety, growing conditions, and leaf type were used in each trial. Genetic differences between cohorts of *M. configurata* and/or the parasitoid species may also have caused this variation.

The variability (i.e. large standard errors) observed, particularly on measurements made on day 13 or later (Figs. 1 and 2), may be associated with unexplained mortality during the experiments, differences between sexes, or stochastic effects because of the relatively small numbers of experimental individuals (n ranged from 5–9 and 7–9 for non-parasitized and par-

asitized hosts in the *B. flavescens* trials and from 10 and 4–9 for non-parasitized and parasitized hosts in the *M. mediator* trials). The genetic diversity of individuals (even though hosts were from the same egg mass and parasitoids from the same female) may have also been a factor.

Natural controls, including parasitoids, have a major impact on bertha armyworm populations (Mason *et al.* 1998) and IPM programs should be developed around them. Chemical insecticides are used when 5<sup>th</sup> and 6<sup>th</sup> instar larvae are present on ripening canola pods (their feeding accounting for more than 86% of total larval consumption). Wylie and Bucher (1977) reported that *B. flavescens*, like bertha armyworm, is univoltine. Although *M. mediator* is bivoltine through most of its range in Eurasia where *M. brassicae* is also bivoltine, Johansen (1997) found it in a univoltine *M. brassicae* population in Norway (although Pivnick [1993] showed that *M. mediator* will diapause, further study is needed to determine if it would be univoltine on bertha armyworm). Adult *B. flavescens* and *M. mediator* are not likely to be affected by current chemical control practices because they attack early (1<sup>st</sup> to 3<sup>rd</sup>) instar larvae and would disappear from the crop before 5<sup>th</sup> and 6<sup>th</sup> instar larvae are present. Even if *M. mediator* proves to be bivoltine in western Canada adults would probably move out of the canola crop seeking alternate hosts in adjacent habitats because no bertha armyworm in the appropriate stages would be available.

Bertha armyworm larvae parasitized by *B. flavescens* feed until they reach the 6<sup>th</sup> instar; thus the parasitoid would be negatively impacted by insecticides because the susceptible host is present in the crop being sprayed. Also, the parasitized larvae continue to feed (causing crop damage) during pod development and the benefits of parasitism by *B. flavescens* are only evident the following year. In contrast, *M. configurata* larvae parasitized by *M. mediator* have ceased to feed (and consumed

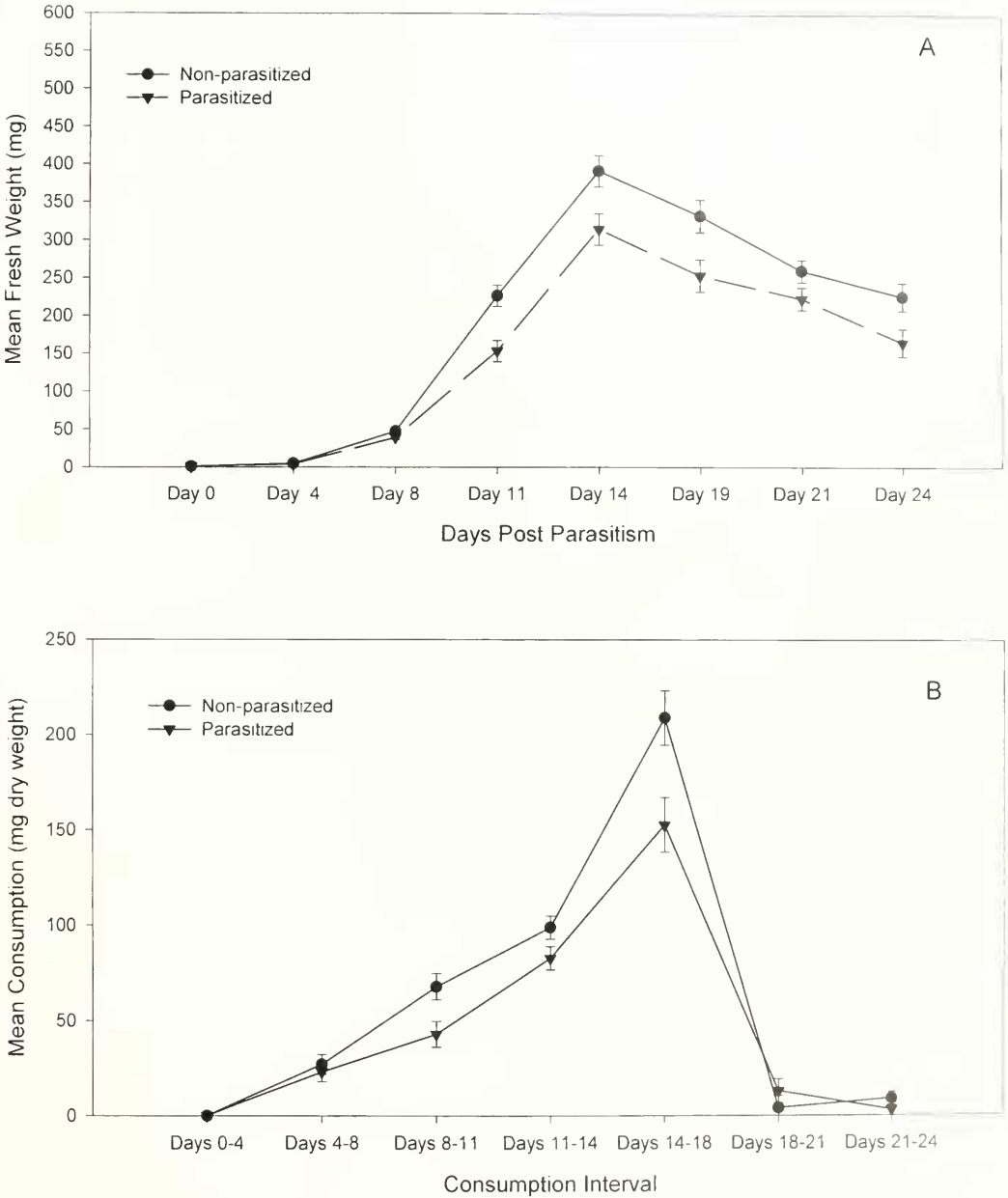


Fig. 1. Effect of parasitism (Trial #1) by *B. flavescens* on *M. configurata*: a) Mean fresh weight ( $\pm$ SEM) of parasitized and non-parasitized *Mamestra configurata* larvae; b) Mean food consumption ( $\pm$ SEM) by parasitized and non-parasitized *Mamestra configurata* larvae.

<20% of the total consumption of non-parasitized larvae) by the time non-parasitized 4<sup>th</sup> instar larvae are present, before the switch to feeding on canola pods by later instar larvae. Further, *M. mediator* have formed cocoons and would likely be

only minimally affected by insecticides used on 5<sup>th</sup> and 6<sup>th</sup> instar *M. configurata*, although this needs to be confirmed. Therefore, *M. mediator* appears to be a good candidate agent for use in the IPM of *M. configurata* because: 1) damage to the

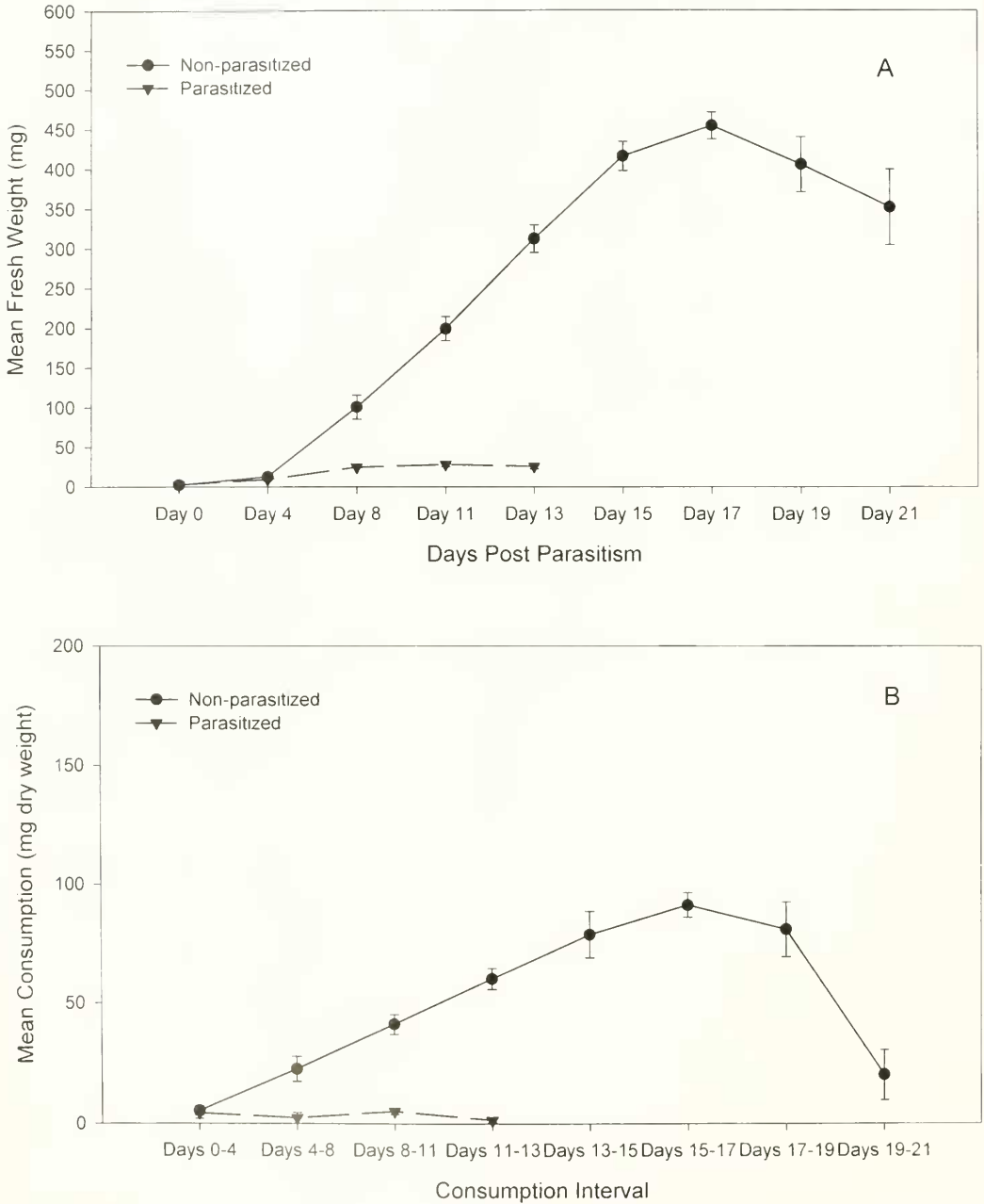


Fig. 2. Effect of parasitism (Trial #1) by *M. mediator* on *M. configurata*: a) Mean fresh weight ( $\pm$ SEM) of parasitized and non-parasitized *Mamestra configurata* larvae; b) Mean food consumption ( $\pm$ SEM) by parasitized and non-parasitized *Mamestra configurata* larvae.

host plant by parasitized larvae occurs when foliage is abundant and ceases before pod development begins; and 2) it should be compatible with other control

agents such as chemical or biological insecticides targeted at 4<sup>th</sup> to 6<sup>th</sup> instar bertha armyworm which are applied after *M. mediator* has eliminated a portion of the pest



population. Caged field release studies are needed to verify these hypotheses.

The results obtained in this study suggest that for *M. configurata* parasitism by *B. flavescens* results in significantly decreased consumption of food (and probably less damage to canola crops) resulting in lower biomass production but does not reduce the length of time that the pest feeds in the crop and parasitism by the braconid *M. mediator* causes a significant reduction in the amount of food consumed and the length of time the host feeds compared to non-parasitized *M. configurata*. Parasitism and the findings presented here should be taken into consideration when developing integrated pest management strategies for the bertha armyworm.

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